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Phase Control During Reconstruction of Holographically Recorded Flow Fields Using Real-Time Holographic Interferometry

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National Aeronautics
and Space Administration

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SUMMARY

A technique of phase control during reconstruction of holographic interferograms is demonstrated in which the recorded scene beam with disturbance present, is made to interfere with the real-time scene beam after the disturbance is removed. The reference phase is adjusted during reconstruction by manipulating either the scene or reference beams. Comparisons are made between the present technique and the two-reference-beam and two-plate techniques, more commonly used for phase control during reconstruction of holographic interferograms for flow visualization.

INTRODUCTION

The advantages of phase control during reconstruction of holographic interferograms, particularly for flow visualization, are discussed in reference 1. Phase control provides one with the ability (1) to control fringe spacing and orientation in finite-fringe interferometry, (2) to achieve maximum sensitivity to phase changes in the flow field, (3) to reject optical noise, and (4) to use heterodyne interferometry for interferogram analysis. Techniques presently used to control phase use either two plates (ref. 2) or two reference beams (ref. 3) to separately record both the flow and no-flow optical fields. In the two-plate techniques, the relative phase between the two reconstructed fields is controlled by adjusting one of the plates with respect to the other (ref. 4), or by adjusting the two plates as a unit (ref. 5). The two-plate techniques are classified as common-path interferometers and have reduced sensitivity to vibrations. In the two-reference-beam technique, one of the reference beams is adjusted during reconstruction to vary the relative phase. Since the two reference beams generally do not follow a common path, the technique is more sensitive to vibrations than the two-plate techniques.

The purpose of this report is to demonstrate an alternate technique for phase control during reconstruction which needs only one hologram plate and one reference beam during the initial hologram exposure. The technique is a modification of real-time holographic interferometry.

In real-time holographic interferometry (ref. 6), a single hologram is made of the no-flow optical field. The no-flow recorded field is then made to interfere with the real-time flow field and the fringe shift is recorded in real time. Just as for nonholographic interferometers, there is no control of fringe spacing or orientation after the interferogram is recorded. Real-time holographic interferometry is relatively sensitive to vibrations, but is very useful for interferometric time-history studies (ref. 7).

In the phase-control method discussed in this report, the flow field instead of the no-flow field is holographically recorded. The hologram is then processed, replaced in its original position, and illuminated during reconstruction, either onsite or at a remote reconstruction lab, with both

scene (phase object now absent) and reference beams. The real-time and reconstructed scene beams will then interfere to form "live" fringes which can be controlled by manipulating one of the beams. Since the two paths of the interferometer are separated before illuminating the hologram, the fringes have vibration sensitivity comparable to the two-reference-beam technique. Reference 8 discusses the generation of a hologram with phase object present, and then reconstruction in real time with both reference and scene beams present, but phase object absent. However, no mention is made of the ability to control the phase of the reference fringes during reconstruction.

DISCUSSION

The experimental arrangement of figure 1 was used to demonstrate this phase-control technique. An argon laser was split into scene and reference beams by a variable-ratio beam splitter with which the two beams could be matched in irradiance at the hologram plane. The scene and reference beams were collimated and intersected the hologram plane at equal angles. During reconstruction, the scene beam transmitting through the hologram and the diffracted scene beam were matched in irradiance to allow maximum fringe contrast in the interferograms. Heat rising from a lit cigarette was used as a phase object. Figure 2(a) is a focused shadowgraph taken with the hologram illuminated only by the reference beam. In figure 2(b), the folding mirror in the reference beam was used to adjust the reconstructed scene beam to be collinear with the real-time scene beam to give an infinite-fringe interferogram. For figure 2(c), the folding mirror was tilted about a vertical axis so that the two beams diverge horizontally, producing vertical fringes. In figure 2(d), horizontal fringes were produced by tilting the folding mirror about a horizontal axis. A combination of horizontal and vertical tilts produces tilted fringes. Differential micrometer screws on the folding mirror are helpful for increased resolution when adjusting for various fringe spacings and orientations. Tilting the hologram about its vertical or horizontal axis also produces vertical or horizontal reference fringes respectively, but with much less sensitivity to tilt angle, as compared to the folding mirror. Rotation of the hologram about its normal axis produces horizontal fringes with sensitivity to angle of rotation comparable to the reference-beam folding mirror. If the scene beam wave front is spherical instead of plane, in-plane translations of the hologram are most easily used for fringe spacing and orientation. Vertical translation produces horizontal fringes while horizontal in-plane translation produces vertical fringes. Out-of-plane translation of the hologram results in curved fringes.

By tilting a glass plate placed in the unexpanded portion of the reference or scene beam, the relative phase can be varied between the transmitted and reconstructed scene beams. Excellent phase-control resolution can be obtained when the glass plate is mounted on a rotation stage having arc-second resolution. For heterodyne interferometry, two acousto-optical cells of slightly different frequency can be used to frequency shift the reference or scene beam to produce moving fringes in the image plane. The optical phase difference can then be very accurately measured with photodetectors as an electrical phase difference.

It is common in holographic flow visualization setups to use a pulsed ruby laser with a wavelength of 693 nm to record holograms (ref. 9). Reconstructions are normally made with a shorter wavelength, either 633 nm or 515 nm. Apart from minor scaling effects, the wavelength change can also introduce aberrations. To simulate this common arrangement, the hologram exposed at 515 nm was also reconstructed at 488 nm. The folding mirror in the reference beam had to be slightly rotated about the vertical and translated toward the incident reference beam to maintain beam overlap on the hologram and to align the reconstructed and real-time scene beams for the interferograms. No focus shift of the reference beam was necessary since the hologram had no optical power (both scene and reference beams were plane waves) and the collimating optics in both beams had no appreciable focus shift between the two wavelengths. Interferograms reconstructed at 488 nm are shown in figure 3. The fringes in the undisturbed portion of these interferograms are not as straight as for the reconstructions at 515 nm, even though third order spherical aberration, coma, and astigmatism are zero when plane waves are used for recording and reconstructing holograms (ref. 10). This deviation of the fringes in the undisturbed region of the interferogram may have been caused by the poor optical quality of the glass substrate on which the hologram emulsion was mounted. Reconstructions at wavelengths other than the recording wavelength may be improved by index matching the holographic plate between high quality optical windows during recording and reconstruction of the holograms. Although geometries other than plane waves for both beams may eliminate third order aberrations, in general the aberrations introduced by reconstructing at a wavelength or geometry differing from that used to record are nonzero, even if the holographic emulsion is mounted on a perfect glass substrate. Note that except for glass substrate effects, the two-plate techniques are partially compensating (fully compensating if the holograms are in contact) since almost equal aberrations are introduced in both flow and no-flow reconstructions when the reconstruction wavelength, or geometry is changed from that used to record the hologram.

CONCLUDING REMARKS

An alternate technique for phase control during reconstruction of holographic interferograms has been demonstrated in which interferograms are formed by combining the reconstruction of the scene beam, recorded with the phase object present, with the real-time scene beam after removing the phase object. This alternate technique is relatively sensitive to vibrations during reconstruction, and is not aberration compensating when reconstructions are made at a different wavelength or geometry from that used to record the hologram. This technique can be simpler to experimentally implement than other phase-control techniques presently used.

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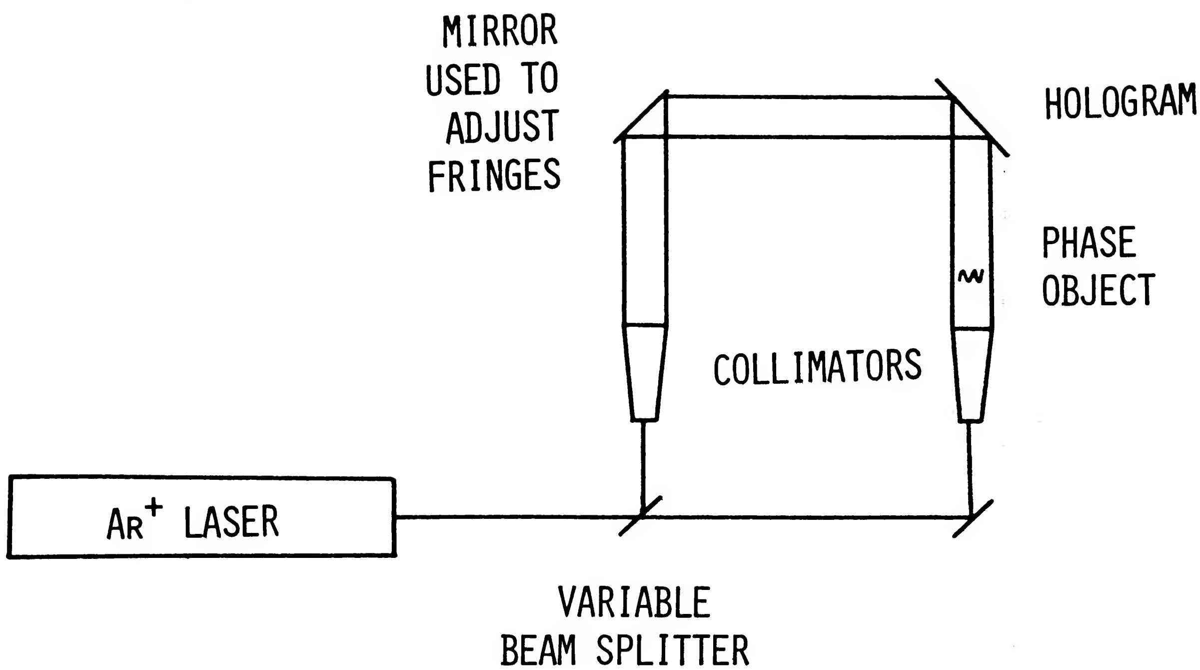
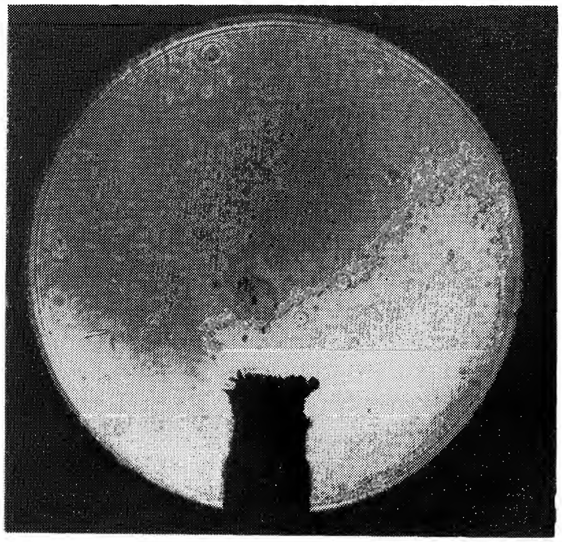
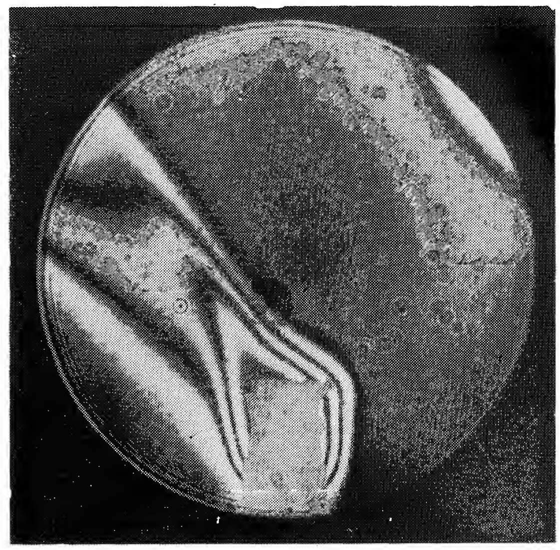


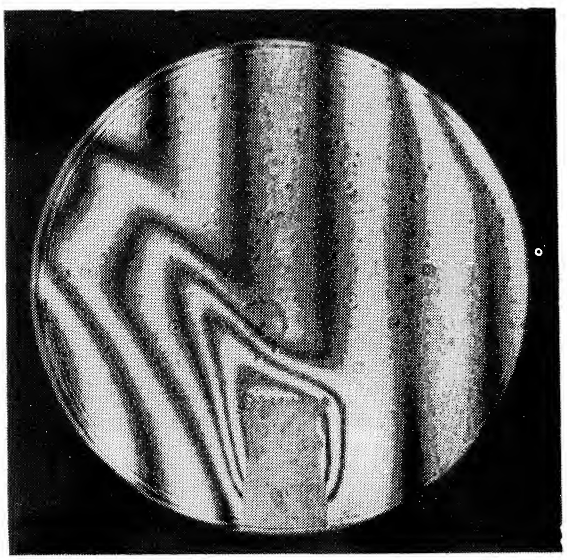
Figure 1.- Experimental arrangement.



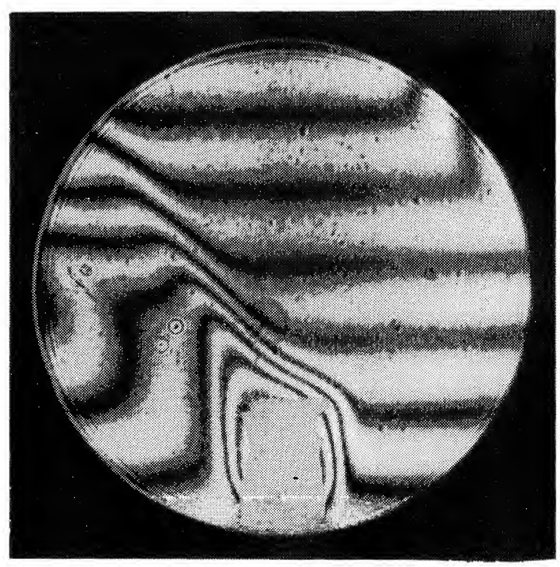
(a) Shadowgraph.



(b) Infinite-fringe interferogram.



(c) Finite-fringe interferogram, folding mirror tilted about vertical.



(d) Finite-fringe interferogram, folding mirror tilted about horizontal.

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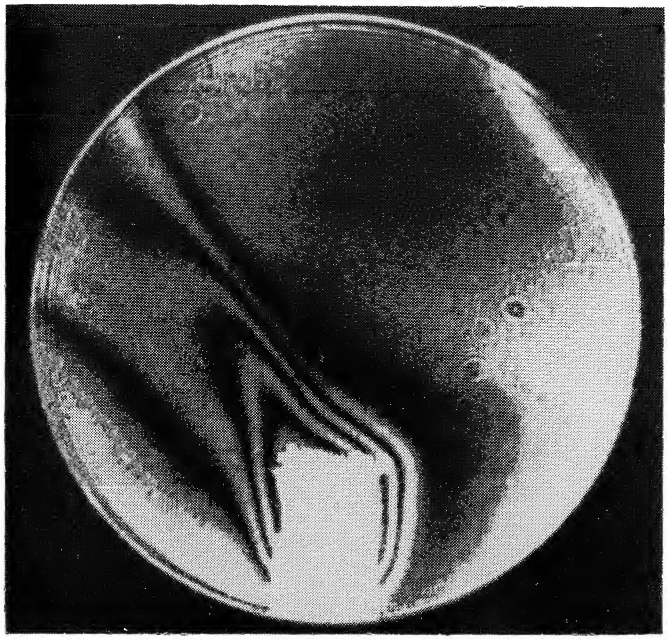
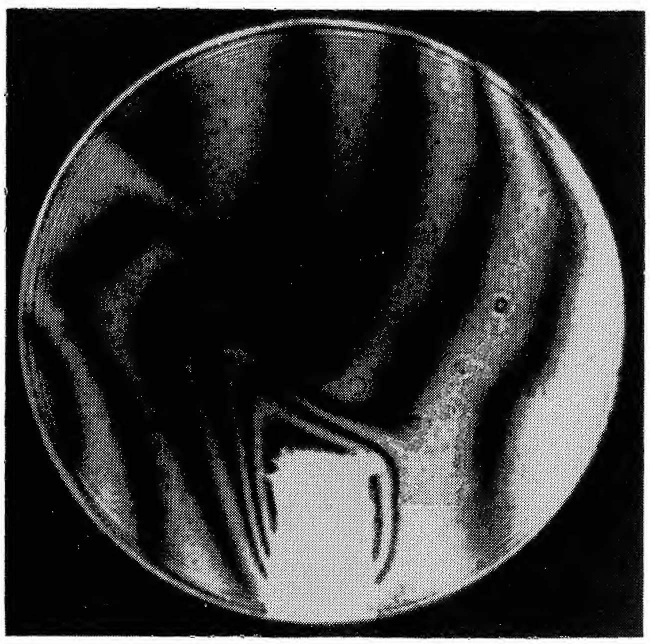
Figure 2.- Reconstructions at 515 nm of hologram recorded at 515 nm.



(a) Infinite-fringe interferogram.



(b) Finite-fringe interferogram.

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Figure 3.- Reconstructions at 488 nm of hologram recorded at 515 nm.

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16. Abstract

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